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WATER IN HIGHWAY SUBGRADES AND FOUNDATIONS

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WATER IN HIGHWAY SUBGRADES AND FOUNDATIONS

The structural integrity and endurance of almost every engineering work is jeapordized by the action of water. The permanence of relatively perishable materials if protected from moisture is illustrated by the ancient buildings, manuscripts, fabrics, and even cereal grains preserved for thousands of years in Egypt which, of course, is noted for the dryness of its climate. The rapid deterioration of all things in a warm, humid climate points the contrast.

In its simplest form then, one of the major problems confronting the civil engineer is the necessity for guarding against or combating the deleterious effects arising from the action of water upon the materials of construction. Everyone is aware of the more spectacular attacks of water such as the destructive wave action along the shores of oceans and lakes; the washing out of bridge piers or damage to embankments by rivers during flood. The necessity for providing waterproof roofs and protective coatings on most buildings and structures is common knowledge. Engineers have also recognized that water has an adverse effect upon the ability of soils to serve as foundations for dams, buildings and even pavements for highways and air fields.

A great deal has been written on the subject of "bearing power" or supporting power of soils and it may be significant to note that this particular field of engineering is generally classed under the heading of "soils mechanics". When a mixture of sand and gravel is mixed with a liquid such as asphalt for the purpose of producing a pavement, such mixtures are invariably referred to as bituminous mixtures or asphaltic pavements even though the amount of asphalt present commonly does not exceed five or six percent by weight of the total mass. When considering the properties of soils or granular base materials, however, engineers rarely mention that they are dealing with a water-soil combination even though the water content commonly ranges between five and thirty percent of the weight of soil.

Narrowing our attention to the special problems surrounding the construction of adequate bases and foundations for pavements, we are forced to conclude that the fundamental relationships depend almost entirely upon the effects of water upon the particular soils in place. The long history of pavement failures due to foundation troubles and inadequate soil support casts no particular credit upon the engineering profession and when such failures continue to reoccur, it is evident that there is a lack of understanding and probably insufficient knowledge of the mechanism by which water is introduced into the soil and of its effects when present. The fact that water is responsible for most of the troubles has, of course, not been entirely overlooked

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because texts on highway engineering have stressed the importance of drainage and for a great many years it has been the practice to provide drainage structures, roadside ditches and numerous varieties of underdrains utilizing tile, perforated pipe, or trenches filled with gravel in an endeavor to "drain out" the objectionable water. Failures have persisted in spite of these attempts and a few engineers have come to realize that it is often impossible to remove or reduce the moisture content by the method of simple drainage.

A few years ago, a Highway Research Board Committee, headed by Dr. Hans F. Winterkorn, was formed to study the problem of non-gravitational water. However, I am not aware that this committee has ever taken any definite action on the problem. Dr. Winterkorn also wrote a paper entitled "Climate and Highways" which was presented at the June 1944 Meeting of the American Geophysical Union (Section of Meteorology). Briefly, Dr. Winterkorn directed attention to a number of facts and factors; some derived from theoretical studies and laboratory investigations; others based upon direct observation of field installations; all of which seemed to indicate that a principal source of moisture accumulation in the soil is through the condensation of vapor in the soil atmosphere. Briefly, the pores in the soil are filled with air and presumably the air is forced in or out of these pores with every change in barometric pressure and probably with changes in temperature.

Other investigators have shown that most engineering materials are pervious to the passage of water in the vapor phase. This includes asphalt films of substantial thickness, most Portland cement concrete, wood, brick, et cetera. Certainly, the more porous structure of soils offers little or no obstacle to the passage of water in the vapor phase. The bulk of literature and instruction dealing with soils for engineering purposes leaves the impression that water can enter only by two very similar means or mechanisms: One, by percolating downward through the soil from rainfall and melting snow. Secondly, the so-called capillary movement by which water is drawn through the pores by a sort of wick action. There is no doubt that water does move by such means. However, there is an increasing amount of evidence that water accumulates beneath pavements under conditions that seem to rule out either direct percolation or capillary action. If engineers are to devise corrective or preventive measures, it is essential that the exact mechanism and path of entrance be known. Unfortunately, there is little in the way of comprehensive data on this subject. Today, there is only a limited amount of recognition that the moisture problem is more complex than hitherto believed, and most of the data is limited to investigations of existing pavements which show varying amounts of moisture in the underlying soil. I know of no comprehensive studies intended to establish the rates at which the moisture accumulates.

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A few years ago, Dr. Miles S. Kersten presented a "Report of Survey of Subgrade Moisture Conditions Under Existing Pavements". This paper was published in the Proceedings of the Highway Research Board in 1944. About the same year, the Materials and Research Department of the California Division of Highways was assigned the problem of investigating the causes for failures and distress often accompanied by mud pumping at the joints in Portland cement concrete pavements. In seeking the causes for these difficulties, a number of pavements were selected representing all degrees of performance at the joints. Holes were cut through the pavements by means of a core drill and the underlying soil sampled in 6 inch layers to a depth of 24 inches. The degree of compaction or density in terms of weight per cubic foot was determined at least for the first two layers encountered. Samples were taken and placed in sealed containers for determination of moisture content. The soils were tested, analyzed and classified, using all of the methods and techniques common to an engineering soils laboratory, and it may be mentioned in passing that there appears to be little if any correlation between these test results or classification schemes and actual performance of the pavement.

For the purposes of this presentation, results were studied in order to determine whether there was any relationship or trend between the moisture content and the nature of the soil. A large number of factors were compared such as the Atterberg limits, the Highway Research Board classification, et cetera, but there was little if any evidence of relationship between these values and the amount of moisture found in the soil. A series of plates or illustrations are included herewith to show the range of moisture distribution in the various layers and these illustrations are offered for whatever they may be worth. These charts, accompanied by a brief description, are included as a sort of appendix and so far seem to warrant only the following general remarks or summary which could hardly be considered to represent definite conclusions.

SUMMARY

It is obvious that the presence or absence of moisture in the soil is a matter of primary importance to men engaged in several different professional activities. The agricultural expert or agronomist is largely concerned if the soils become too dry to support plant life. The highway engineer has reason for concern when the soils accumulate enough moisture to become lubricated and hence lose ability to support pavements subjected to heavy loading.

It is evident that the construction of tight, impervious pavements does not prevent moisture from entering and accumulating in the soil beneath the pavement. It is evident that the construction of asphaltic membranes or the presence of an old pavement beneath a layer of gravel or soil does not prevent the intermediate layer from becoming saturated.

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In other words, a layer of soil placed as a "Sandwich" between two layers of relatively impervious pavement usually accumulates more moisture and reaches a higher degree of saturation than if placed directly on the ground. The assumption that water enters the soil by soaking downward from the surface or by capillary action from below seems to be inadequate to explain the amount of moisture that has been found beneath pavements in a great many cases. This leaves as a remaining possibility the movement of moisture in the vapor phase through the pores of the soil and the condensation of vapor due to either changes in temperature or in pressure. It has been pointed out that soils will hold more moisture by adsorption when temperatures are low and will yield up this adsorbed moisture in the form of free water when temperatures rise. Direct observation of roadway performance seems to lend ample support to this theoretical concept. So far as California experience is concerned, we lack convincing or direct proof to establish the path by which moisture enters the subgrade soil. The present situation may, therefore, be summed up thus;

Admitting that moisture can enter through porous pavements or leaky surfaces, and recognizing that moisture can migrate upward by "capillary action" to produce saturation when the water-table is near the surface, there remains the strong probability that moisture also accumulates as a result of water vapor moving freely through the pores in the soil and condensing upon the soil particles when subjected to a drop in temperature. Variation in temperature would be most marked near the surface of the ground or at the underside of the pavement and when sufficient water has accumulated, it would migrate downward by drainage or by capillary action. It is not clear, however, whether the water vapor characteristically migrates upward from a submerged water-table (which may be many feet below the surface) or whether it is carried in by the movement of air from the outside atmosphere--or both.

A proven answer to these questions will clarify the problem of designing preventive or corrective methods and should enable the Highway Engineer to proceed with much greater intelligence or assurance than is possible at the present time.

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The following charts illustrate some of the relationships between the characteristics of the soil and the amount of moisture found in the soil immediately beneath Portland cement concrete pavements in California.

As a part of the investigation, holes were bored in the concrete pavement using an eight inch diameter diamond bit, and samples of the underlying subgrade soil were taken for a depth of 24 inches.

Separate samples were secured for each six inch depth beneath the pavement and the density in place of the first two layers was determined by the sand volume method whenever possible.

The first five charts, Figures 1 to 5, inclusive, illustrate the typical types of moisture distribution. Figures 1 to 4 represent borings where the soil was of the same character for the entire depth. Figures 6, 7 and 8 show other soil moisture relationships.

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Figure 1 shows an example of comparatively uniform moisture distribution under a pavement that had been down for 13 years at the time the samples were taken.

The soil is a very uniform sand-micaceous silt and the moisture content of approximately 7% represents 44% of saturation.

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Fig I

CHART SHOWING

SIMILAR MOISTURE WITH DEPTH

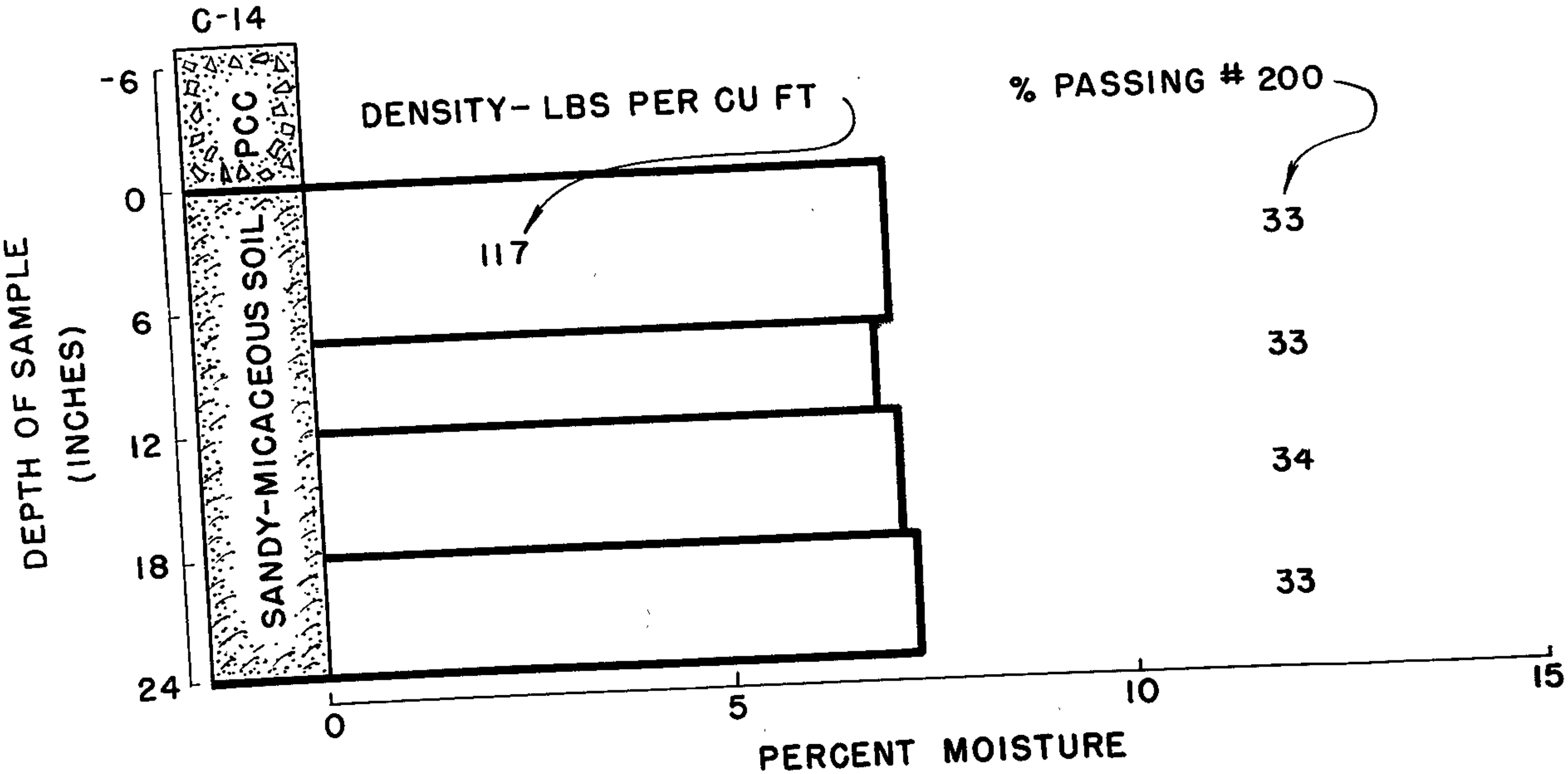

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Figure 2 - A number of samples were drilled where the moisture content was greatest in the upper layer, while the composition of the soil is virtually identical throughout the depth samples. This is typical of this type of moisture distribution.

This pavement had been in place for 13 years.

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Fig 2

CHART SHOWING

MOISTURE DECREASE WITH DEPTH

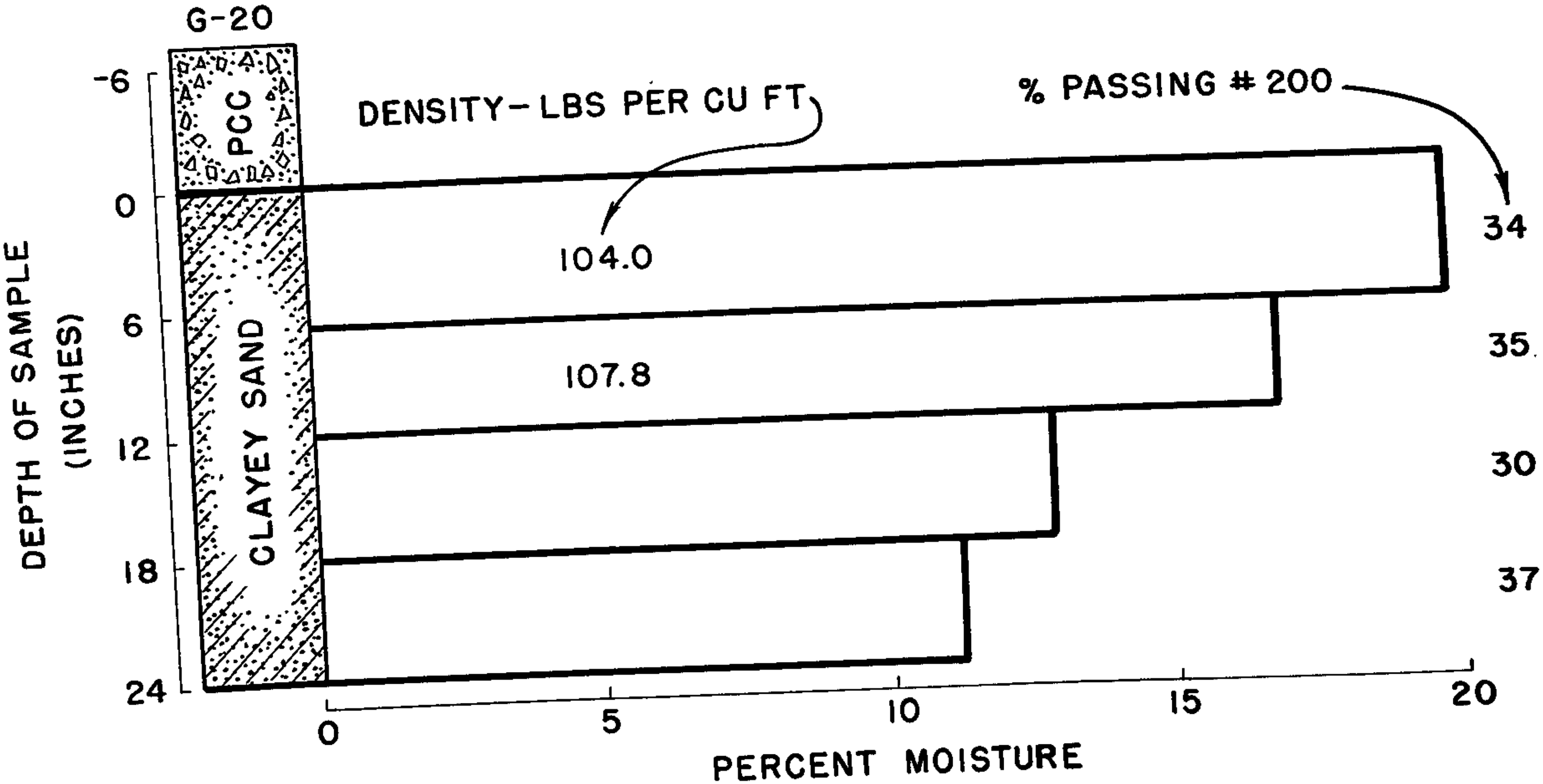

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Figure 3 illustrates the moisture distribution in reverse of Figure 2. In this case, the moisture content increases consistently with increasing depth below the surface. The soils are very heavy silty clay type containing more than 50% passing No. 200.

The pavement was 11 years old when the samples were taken.

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Fig 3

CHART SHOWING

MOISTURE INCREASE WITH DEPTH

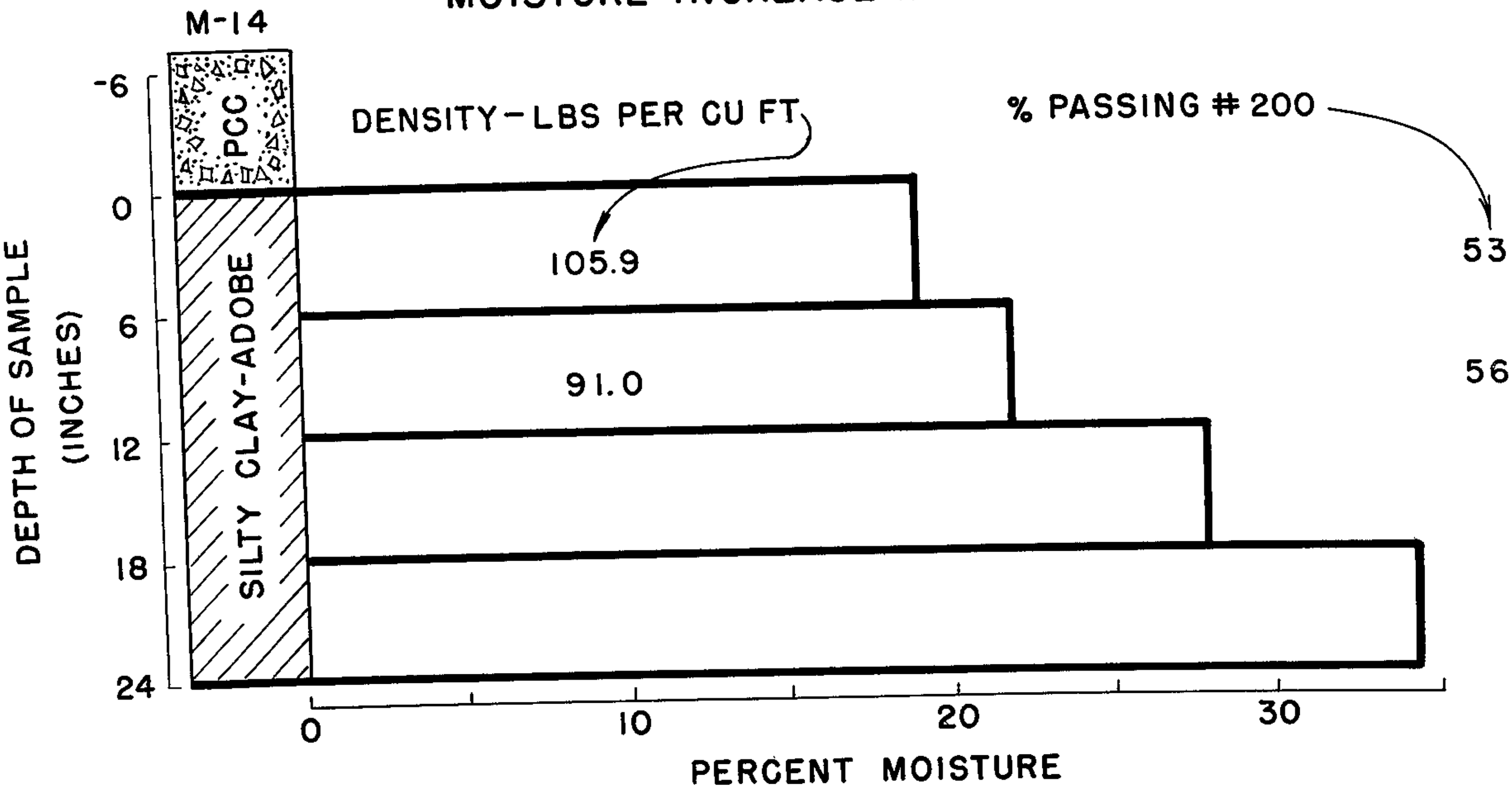

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Figure 5 - This figure is included to show the marked differences in the moisture content where each layer of the soil is of a different type composition.

This particular boring was taken in a location where the first six inch layer beneath the pavement consists of a light-weight porous, granular material, presumably of volcanic tufa.

The second layer represents an old road surface composed of an oil mixed surface on a crushed rock base.

The third is a layer of sandy material imported as a subbase under the original bituminous surface, and the final layer is a local black adobe soil.

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Fig 4

CHART SHOWING

MOISTURE ERRATIC WITH DEPTH

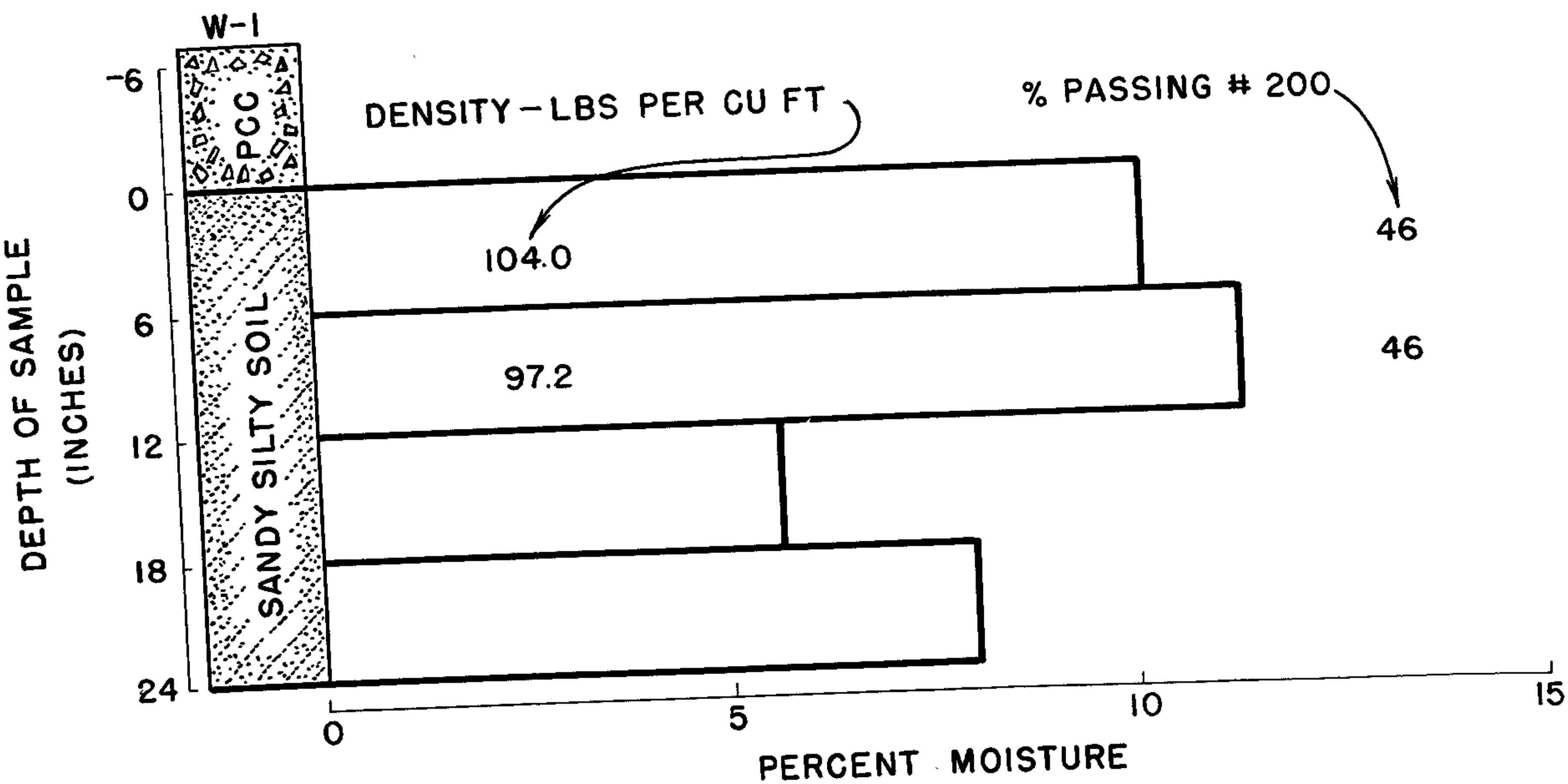

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Figure 4 represents a boring taken through the pavement into sandy, silty soil where the moisture distribution is somewhat erratic. No definite pattern evident.

The pavement had been down 15 years.

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Fig 5

CHART SHOWING

VARIOUS CONDITIONS

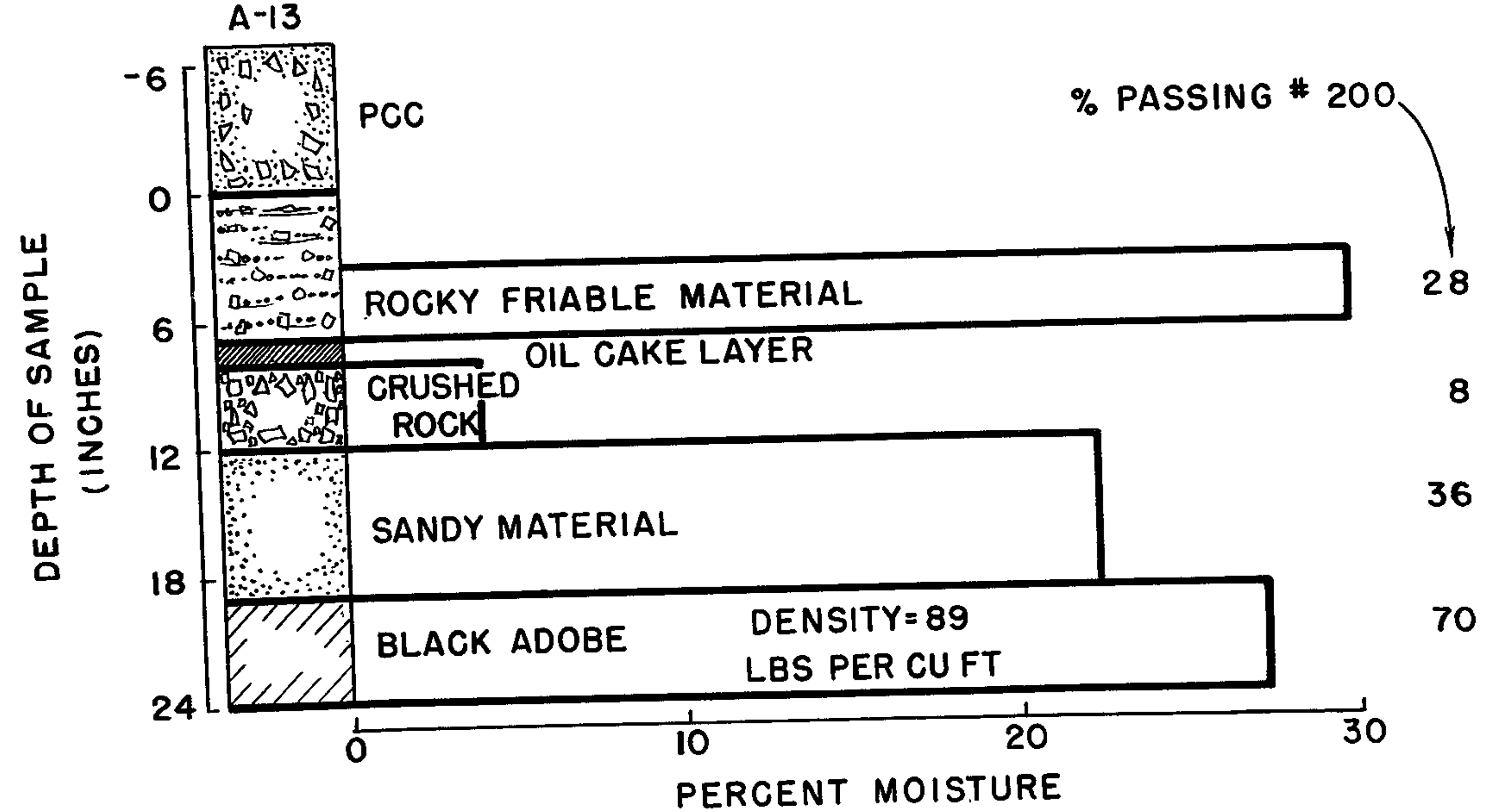

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Figure 6 - This chart illustrates the degree of saturation compared to the age of the pavement. These points seem to indicate that the rate at which moisture accumulates may be quite slow.

While the data are far from being conclusive because all pavement samples were at least five years old when samples were taken, it is undoubtedly true that in some cases interlying soils may have been saturated at the time of construction. Nevertheless, there appears to be a trend indicating that it may require a period of more than ten years for complete saturation to develop.

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Fig 6

CHART SHOWING

DEGREE OF SATURATION OF FINE GRAIN SOILS
VS
AGE OF PAVEMENT

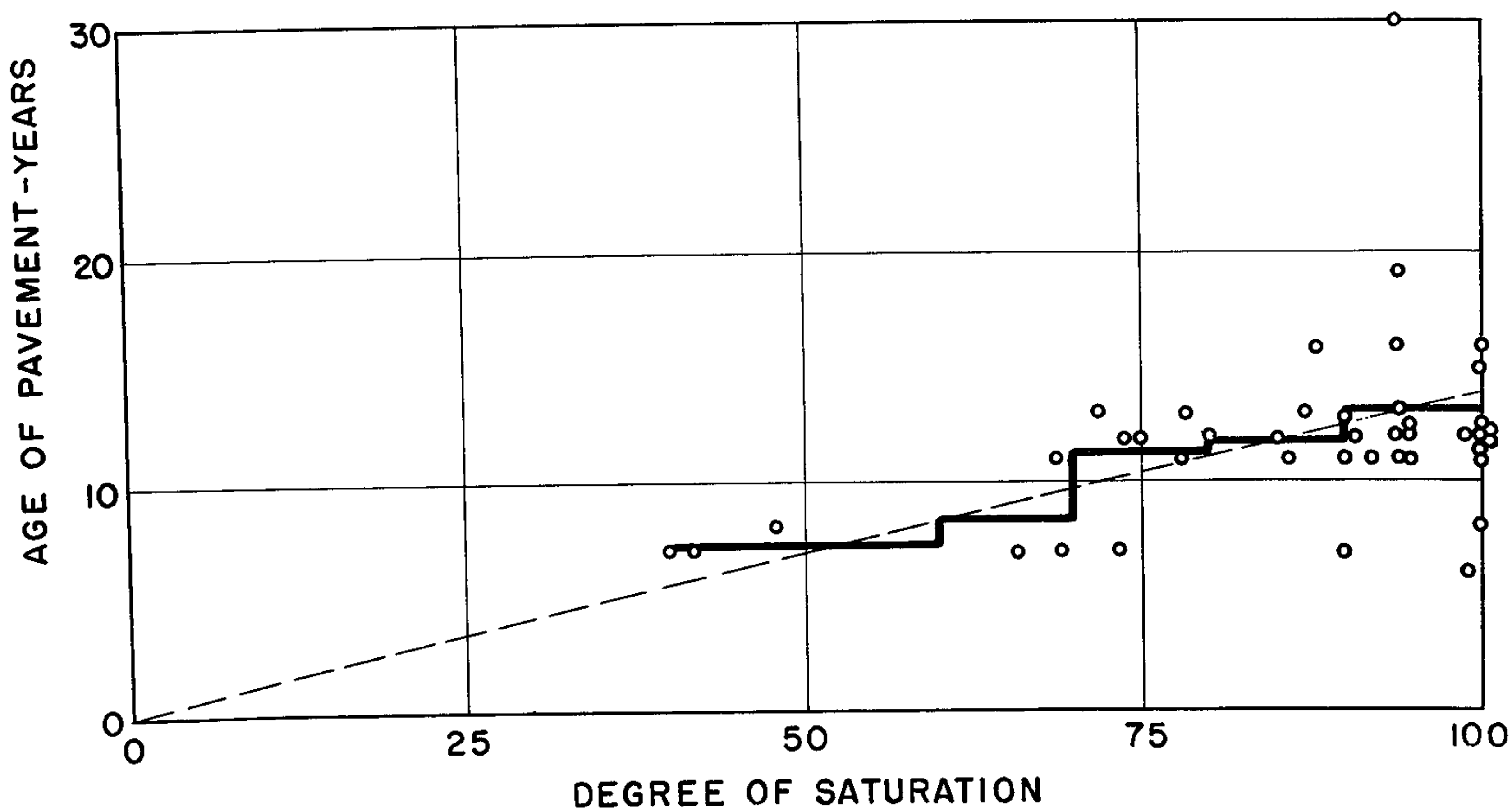

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Figure 7 is a chart that illustrates the relationship between the calculated surface area of the soil particles and the amount of moisture. This relationship apparently represents the only discernable trend between characteristics of the soil and the moisture present. While the relationships indicated are not sharp or precise, it is also true that the values shown for surface area equivalents are only rough approximations and may be considerably in error for the finely divided clays or soils containing an appreciable amount of colloidal sizes.

The indication that there is some relationship between particle surface area and the moisture content may lend support to the theory that moisture accumulates largely as a result of condensation from water vapor.

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Fig 7

SURFACE AREA vs PERCENT MOISTURE

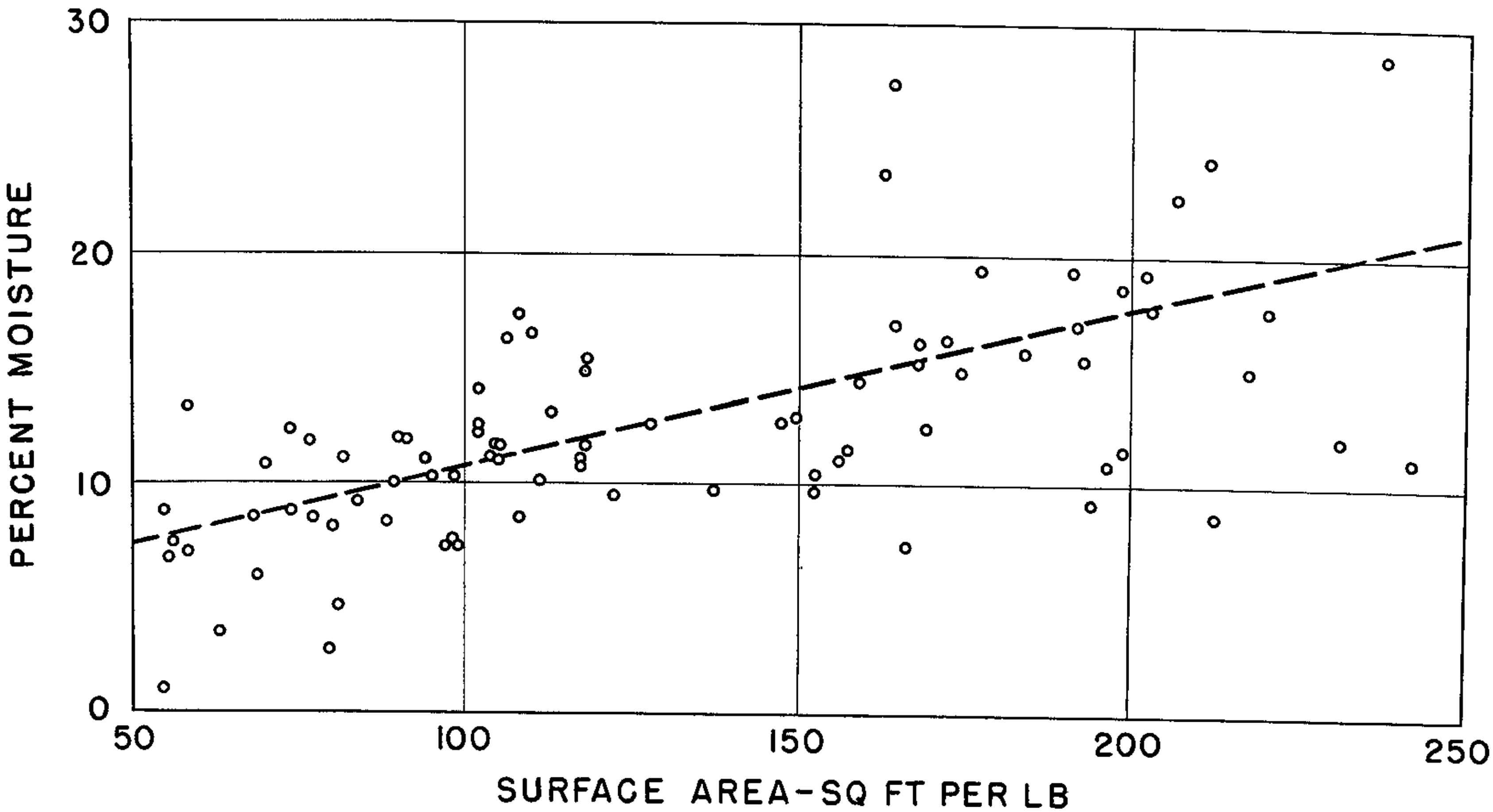

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Figure 8 - This chart shows the relative number of samples representing the various degrees of saturation.

While the average of all samples taken corresponds to a moisture content of approximately 79% saturation, it is evident that a relatively high percentage have approached or reached saturation.

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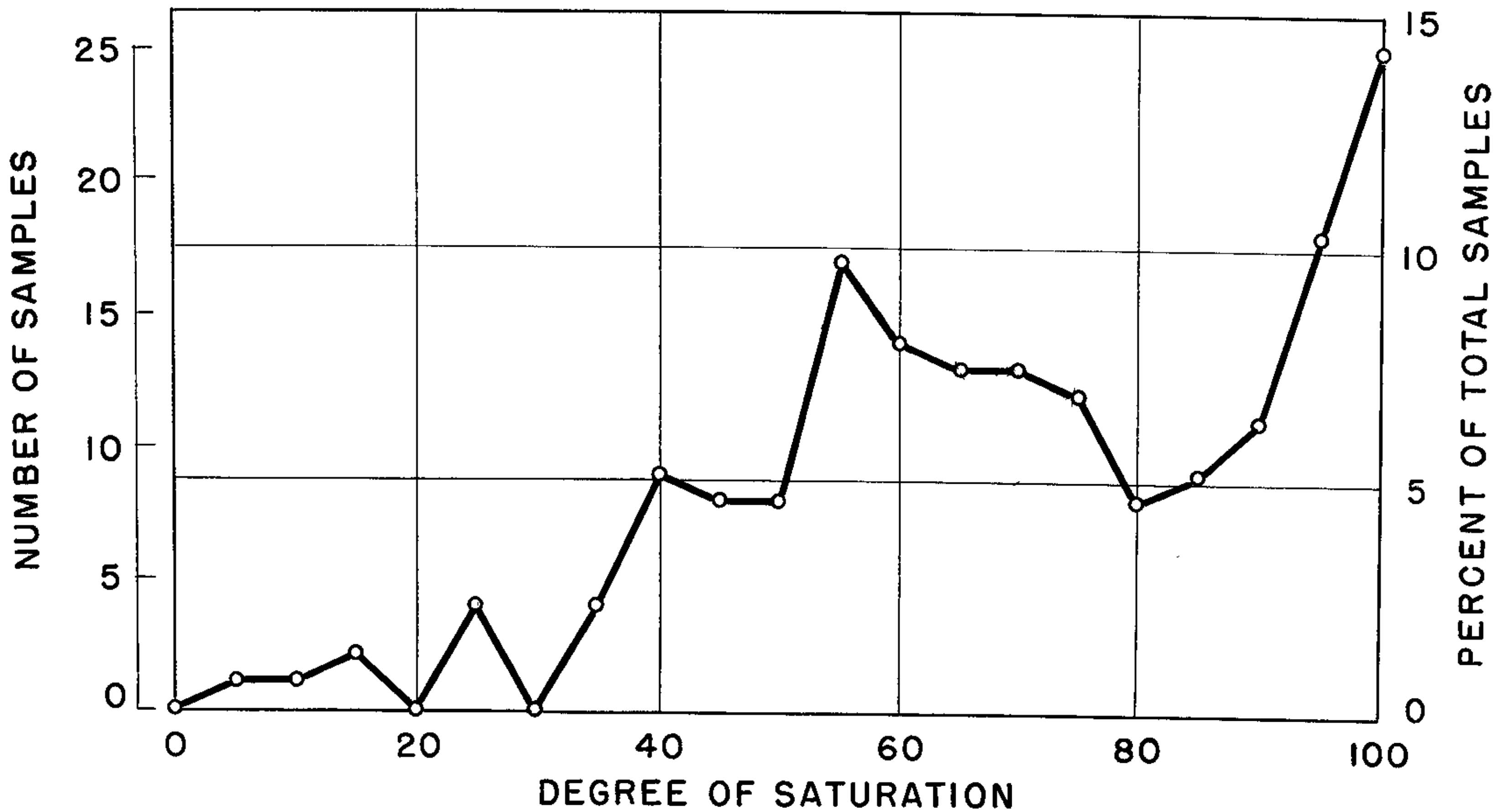
Fig 8

DEGREE OF SATURATION vs NUMBER OF SAMPLES

175 SAMPLES USED



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